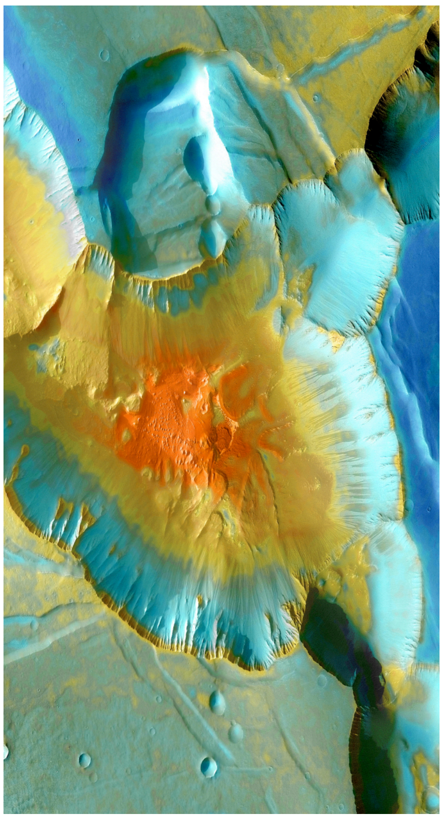
National Aeronautics and Space Administration

2006 Update to Robotic Mars Exploration Strategy

2007-2016



November 28, 2006

By the
Mars Advance Planning Group 2006

Mars Advance Planning Group 2006 (MAPG)

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Cover Photo: As volcanic activity began to stir in the region adjoining Tharsis, it stretched and fractured the Martian crust forming a depression 4 kilometers (13,000 feet) deep. As cracks and faults opened, ice and water in the subsurface escaped, making the ground collapse. This false-color infrared mosaic, combines visible wavelength daytime images with color stretched nighttime infrared images that record the predawn temperature of the surface. Warm, coarse and rocky, portions of the surface are shown in redder tints while cooler, dust mantled parts of the ground are shown in blue tints.

Spacecraft: Mars Odyssey
Instrument: THEMIS (Phil Christensen, PI)
Images Acquired: April 2003 to September 2005
Location: Noctis Labyrinthus

INTRODUCTION

In July 2005, NASA initiated a Mars program strategic planning process through the formation of a strategic planning team, which became known as the Mars Advance Planning Group 2006 (MAPG), under the leadership of Daniel McCleese and Michael Meyer. On the basis of a series of discussions regarding science/programmatic priorities, scientific lines of inquiry, and engineering implementation options, the MAPG prepared a draft white paper summarizing planning options through the middle of the next decade. This report was updated after iteration with the Mars Exploration Program Analysis Group (MEPAG) in late 2005, and was updated again after the release of the U.S. Federal budget in February 2006. The March 2006 version of this planning document (McCleese et al., 2006) was then presented to the NRC for its formal review. The NRC carried this out by forming the Mars Architecture Assessment Committee (MAAC), which responded in July 2006 with a detailed set of review comments, including 12 specific recommendations to NASA (NRC, 2006a; summarized in Appendix 1 of this report). Five of those are sufficiently addressed in a letter from Mary Cleave (Associate Administrator for NASA's Science Mission Directorate, Appendix 2) to Dr. Reta Beebe (Chair, MAAC) dated July 2006, and require no further comment from MAPG. The other seven recommendations were referred to MAPG for its consideration. The purpose of this report is to document those discussions and findings.

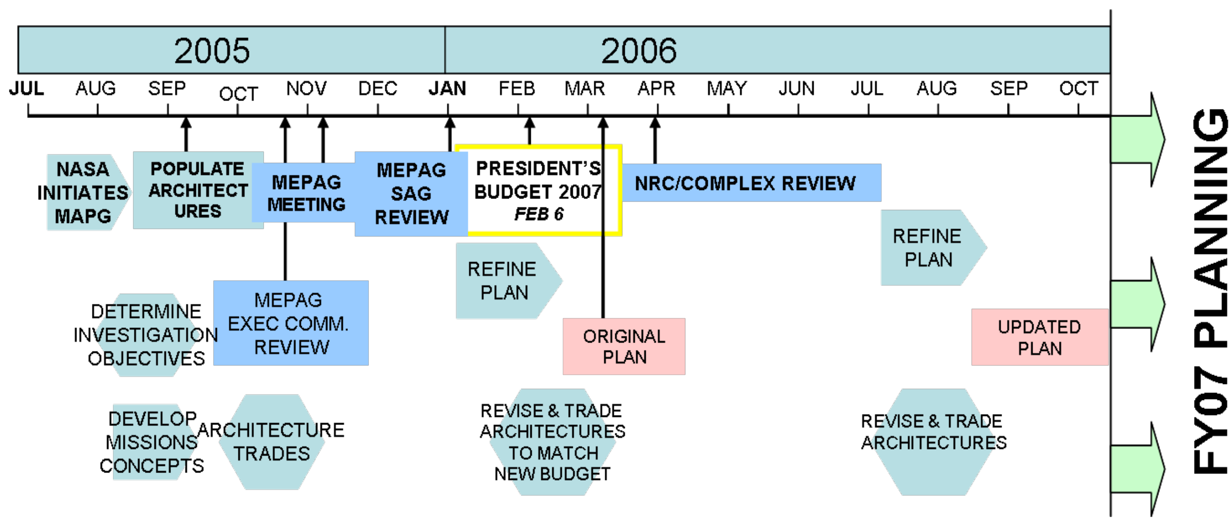

Figure 1. Timeline illustrating the 2005-2006 Mars Program planning process. The two planning documents highlighted in pink represent the original MAPG report (March 2006), and the "update report" (this document).

This report is structured as an addendum to the March 2006 MAPG document (McCleese et al., 2006), rather than as a replacement. Although the MAAC raised some questions, it did not find that the March 2006 document has substantial omissions or errors. In addition, the programmatic context of the Mars Exploration Program (MEP) has evolved since March 2006. Although some changes to the March 2006 report would therefore be appropriate to bring it up to date, MAPG also recognizes that Mars strategic planning is a dynamic process. As of this writing, there are four orbiters and two rovers at/on Mars actively returning data, so there is a steady progression of scientific discovery and evolution of scientific priority. [MGS operational status was uncertain as this report went to print.] *All* Mars planning documents slowly drift out of currency as exploration proceeds and circumstances change. Thus, rather than rewrite the March 2006 document, MAPG prefers to retain that as a snapshot in time of our state of strategic thinking.

PLANNING QUESTIONS POSED BY THE NRC MARS ARCHITECTURE ASSESSMENT COMMITTEE (MAAC)

The seven MAAC recommendations considered by MAPG (see Appendix 1) can be organized around five general topics:

1. The architecture analysis and trade-off process
2. Network science options
3. Astrobiology Field Laboratory timing relative to the 2009 Mars Science Laboratory
4. Mars Sample Return technology investment
5. The decision strategy for 2016

1. The Architecture Analysis and Trade-off Process (Recommendation #6)

> Clarify how trade-offs involving mission costs versus science were made for the various launch opportunities to justify the rationale behind the proposed sequence of specific missions and the exclusion of others.

In general, planning trade-offs for future Mars missions involve four kinds of inputs: science priorities; NASA strategies and priorities; programmatic goals; and cost, technical, and policy considerations.

Science priorities. The MAPG (and similar past planning groups) had access to science priorities for Mars exploration from two sources. The NASAAdvisory Council and the National Research Council recommend priorities related to both missions and scientific approaches to NASA at irregular intervals. Much of the advice of the National Research Council comes from the Space Studies Board (SSB; one of 14 operating units of the Engineering and Physical Sciences Division of the NRC; provides independent, authoritative advice on all aspects of space science and applications), or the Committee on Planetary and Lunar Exploration (COMPLEX; one of seven standing committees of the SSB; advises the Space Studies Board on the entire range of planetary system studies that can be conducted from space as well as on ground-based activities in support of space-based efforts). The primary, relatively recent reports that contain Mars recommendations are listed below:

- Strategy for Planetary Exploration of the Inner Planets (COMPLEX, 1978)
- Space Science in the 21st Century (SSB, 1988)
- Update to Strategy for Planetary Exploration of the Inner Planets (COMPLEX, 1990)
- An Integrated Strategy for the Planetary Sciences: 1995-2010 (COMPLEX, 1994)
- Review of NASA's Planned Mars Program (COMPLEX, 1996)
- On NASA Mars Sample-Return Mission Options (COMPLEX, 1996)
- On NASA's Office of Space Science Draft Strategic Plan (SSB, 1997)
- On Assessment of NASA's 2000 Solar System Roadmap (COMPLEX, 2000)
- Assessment of Mars Science and Mission Priorities (COMPLEX, 2003)

- New Frontiers in the Solar System: An Integrated Exploration Strategy (NRC, 2003)
- Review of Goals and Plans for NASA's Space and Earth Sciences (SSB, 2005)

Much of the advice relating to Mars from the NASA Advisory Council (NAC) is based on analysis work conducted by the Mars Exploration Program Analysis Group (MEPAG), which has recently been reorganized as a part of the NAC structure. NASA's Science Mission Directorate (SMD) has a standing request for MEPAG to maintain an up-to-date analysis of the scientific investigations and measurements, in priority order, that would contribute to achieving four high-level programmatic scientific goals of MEP. This is done through a multi-disciplinary "bottoms-up" process involving the Mars scientific exploration community and an annual reassessment of the Goals and Objectives document, first prepared in 2001 (for the current version, see MEPAG, 2006).

The NASA-SMD Strategic Plan. The NASA Science Mission Directorate and its organizational predecessors maintain strategic plans that have benefited from formal advice from the National Research Council and the NASA Advisory Council. Examples of these plans include NASA (2003a), NASA (2003b), and NASA (in prep.).

Programmatic Goals. The Mars Exploration Program has six programmatic goals of relevance to planning future missions (Section 1.4.3 of the MEP Program Plan). It is important to note that these are explicitly stated as goals, not requirements.

I. **Maintain a continuous operational presence at Mars**
   - Ensure that operating orbiters or landers are able to provide continuous and long-term observations of the changing Mars natural environment.
   - Provide uninterrupted telecommunications relay capability for US, and international partners as appropriate.

II. **Launch at least one mission to Mars at each 26-month opportunity**
   - Maintain a capability to assure that there is at least one mission ready to launch at every Mars launch opportunity. These opportunities will include Scout-class, competitively selected PI-led missions as well as strategic, facility-class missions carrying competitively selected instruments.

III. **Provide continuing improvements in technical capabilities of Mars missions by investments in technology development**
   - Conduct a technology investment program to develop, mature and test technology advances that enable future Mars Missions with a recommended investment goal of 5-10% of the overall MEP budget.

IV. **Capitalize on measurement opportunities that contribute to the advancement of knowledge for future human exploration of Mars, in collaboration with ESMD.**
   - Ensure scientific measurements and technologies that can enable human exploration of Mars are considered for flight, that data is exploited to support the Vision, and opportunities to fly instruments of opportunity from ESMD are exercised on a mutually agreed-to basis.

V. **Ensure that Mars exploration activities are publicly engaging and incorporate current Mars mission science and technological achievements into a long-term portfolio of formal and informal education and public outreach activities.**

- Increase the number of participants and the depth of their experience through progressive learning, in alignment with SMD/MEP guidance and complementing NASA Strategic Communications efforts.
- Strategically and systemically engage participants, especially students, who are traditionally under-represented in the fields of science, technology, engineering, and mathematics.

<u>Cost, Technical and Policy Considerations.</u> In carrying out the exploration of Mars, the Mars Exploration Program considers financial constraints, engineering heritage, the possible or planned state of future technology readiness, infrastructure needs, policy constraints (e.g., planetary protection), and the logical consequences of precedent relationships in designing future mission sequences.

During the time period under consideration, the most important infrastructure need is for telecommunications, especially orbital assets that can be used for data relay locally at Mars (for additional detail, see Section 5.3 of McCleese et al., 2006). Our experience with the Spirit and Opportunity rovers has shown that it is very effective to relay data from the Martian surface through science orbiters back to Earth. However, since such orbiters have limited lifetime, we need to plan for their replenishment. In addition to relaying the data to Martian orbit, the data from missions on the surface of Mars need to be transmitted to Earth where they can be received by the Deep Space Network. The current DSN infrastructure imposes limitations on the maximum rate that data can be transmitted from Mars to Earth, in turn limiting the science return from high performance instruments (e.g., multispectral imagers) both in orbit and on the surface. The optimal functioning of the DSN is not a uniquely Mars issue, but it is certainly one that is relevant to Mars planning. These issues were represented within MAPG's discussions through the Mars Program Chief Telecommunications Engineer.

Technical concepts for mission design, spacecraft, flight operations and required technology developments were derived from the MEP Advanced Studies Office, which made use of JPL Team-X for cost estimation. Conceptual payload characteristics were derived from MEPAG Science Analysis Groups or the Advanced Studies Office (note: in order to generate a cost estimate, it is typically necessary to specify the payload and how it will be used. This information is used for scoping purposes only, and does not imply instrument selection). Cost estimates for mission development, flight operations, and needed technology development (if any) were developed and profiled over multiple fiscal years. Launch vehicle cost estimates were obtained from KSC. Data from past mission experience were used as analogy for estimating both the budgets and mission schedules.

The costs of candidate sequences of missions were estimated and compared to an assumed future budget. Mission sequences were judged to be financially acceptable if the cumulative cost was within about $100 million of the revenue model through 2013, and within about $200 million through 2018. Although there is an imperfect ability to forecast the budget of the Mars Exploration Program 12 years in the future, in order to avoid unrealistic expectations, MAPG did not consider mission sequences that are significantly discordant with this financial model.

The MAPG was configured with a mixture of personnel who could provide expertise in each of the above areas. Not surprisingly, given the diverse nature of the scientific questions and the diverse nature of the constraints, the MAPG team had divided opinions on certain planning options. In order to preserve the possibility for additional input from future advisory bodies, mission results, and technology development, multiple options were built into the proposed architecture. Where decisions were needed on non-consensus issues, the Lead Scientist and the Chief Scientist for MEP made them. As the MAPG Co-chairs, they were responsible for appropriate balancing of the above inputs.

2. Network Science Options (Recommendations #1, #10, #11)

> (1 & 10) Include the Mars Long-Lived Lander Network in the mix of options for the 2016 launch opportunity. (11) If the Mars Long-Lived Lander Network cannot be implemented in the period under consideration, provide for an effort to make some of the highest-priority measurements on the landed missions that are included in the proposed Mars architecture.

A planning premise used within the Mars Exploration Program for the past several years has been to make progress towards each of the four MEPAG goals, and to treat the Life goal, as "first among equals." This simple statement of priority is based on the integrated advice the Mars Exploration Program has received from its various advisory bodies over most of the past decade. Within the presently planned Mars flight architecture, each of the next three missions (2005-MRO, 2007-Phoenix, 2009-MSL) have scientific objectives that are related to the Life goal. Specifically, these investigations will give us critically important new insight into the habitability potential of Mars in both space and time, and in the case of MSL, in a detailed and quantitative way for one site. If strongly encouraging life-related data were to be delivered by one of these three missions, our most effective response would be the Astrobiology Field Lab (AFL) in 2016 or 2018. The emphasis on the Life goal, coupled with financial constraints, has delayed plans to implement network science. Since the Mars Long-Lived Lander Network (ML^3N) would have minimal direct value as a follow-up to a habitability discovery by MRO, Phoenix, or MSL, it would be inconsistent with the overall priority structure to move the network mission ahead of AFL if the consequence would be to delay the possibility of AFL beyond 2018. While we do not know in advance that AFL will be the mission of choice in 2016-2018, it is necessary that we protect that option.

MAAC recommended that MAPG expand its consideration of options for network science within the proposed Mars Architecture. In response to this recommendation MAPG identified four basic options to conduct network science, or some of its component investigations, early in the mission queue.

> Option A: ML^3N as an option for 2016. MAPG looked at the implications of including the Mars Long-Lived Lander Network (ML^3N) in the mix of options for the 2016 launch opportunity. MAPG agrees with the MAAC that this mission has very attractive science, and that it will contribute an entirely new type of knowledge to our understanding of Mars as a system. MAPG was asked to base its planning on a financial model where future funding is the inflation-adjusted equivalent of about $600M per year (in FY06

dollars). Based on current cost estimates, flying the ML^3N mission in 2016 would preclude all but the simplest versions of AFL until the 2020 launch opportunity, and in addition would require a descoped version of MSO. This one to two opportunity slip of AFL from its earliest possible launch must be weighed against the two-opportunity promotion of ML^3N. However, if a modest increase in the program budget (perhaps 10-15%) were possible in the future, the mission sequence 2013-MSO, 2016- ML^3N, 2018-AFL would represent an extremely attractive balance between direct life-related measurements and broader characterization of Mars as a system.

Option B: Augmentation of MSO. A new technical option was presented to the MAPG in which multiple (two to four) network landers could be launched in 2013 using MSO as the cruise carrier and communication relay. Preliminary analysis shows that the 4-node option provides considerable overall savings compared to the stand-alone ML^3N mission and might allow this high-priority science to be addressed earlier in the program than would otherwise be possible. However, with the current financial constraint of $600M/yr, this large 2013 investment would preclude the financial capability to follow-up with missions in both 2016 and 2018, and would therefore affect the possible timing of AFL.

Option C: Single geophysical lander augmentation of MSO. A single geophysical lander could be flown on MSO. A case can be made that a geophysical pathfinder would generate some valuable science (although not nearly as valuable as a 4-node geophysical network). From a single station, it would be possible to determine the level of seismicity on Mars, which would give a measure of the current level of tectonic and volcanic activity; this is fundamental information about the dynamics of Mars. Doing this geophysical pathfinder in 2013 would provide the potential of additional landers in subsequent years, perhaps by our international partners, and set things up for the full ML^3N mission three opportunities later (in 2020) to achieve the full complement of geophysical science. However, with this scenario and AFL in 2018, a mission launching in 2016 would be precluded without a budget augmentation. Alternatively, AFL and subsequent missions would incur a further delay.

Option D: Augmentation of a 2016-2018 rover mission. A stand-alone geophysical package could be included on a landed mission in 2016-2018 (e.g., either AFL or Mid-Rovers). However, our present concepts for rovers in the 2016-2018 time period are such that there is likely to be a shortage of spacecraft resources for completing the mission's primary objectives, rendering it unlikely that additional resources could be spared for a geophysical package.

A complete evaluation of the science and engineering options that could be included in the geophysical investigations on the 2013 orbiter [Options B and C above] requires detailed study by an analysis team that includes a community-based science sub-team. This activity is proposed for FY07.

3. Astrobiology Field Laboratory timing relative to the 2009 Mars Science Laboratory (Recommendation #2)

> (2) Consider delaying the launch of the Astrobiology Field Laboratory until 2018 to permit an informed decision of its merits and the selection of an appropriate instrument complement in the context of a mature consideration of the results from the Mars Science Laboratory and other prior missions.

For the past decade, scientific results from the Mars Exploration Program have been progressively more encouraging regarding the possibility of life (either past or present) on Mars. If this trend continues, by the middle of the next decade the life-related part of the Mars program will have built towards the Astrobiology Field Laboratory (AFL), Mars Sample Return (MSR), or both. The principal scientific objective of the Mars Science Laboratory is specifically focused on habitability, and it is very possible that MSL could generate a compelling discovery to which there would be a strong desire to respond with AFL. However, it is also possible that important life-related discoveries could be made by MRO or Phoenix, for which an AFL response would be warranted. Thus, AFL should not be considered to be uniquely dependent on MSL discoveries. In fact, some scientists argue that sufficient discoveries have *already* been made (by MGS, ODY, and/or MER), and that no further justification is needed to commit to planning for AFL. Although the MAAC is correct that there is probably not enough time to design a 2016 AFL mission as a specific response to a discovery by 2009 MSL, there may be sufficient justification to fly AFL in 2016 independent of MSL.

What is "AFL"?

Part of the difficulty in discussing AFL is that the term "Astrobiology Field Laboratory" is not well defined, and it means different things to different people.

For the purpose of this report, the term "AFL" is used to refer to a substantial landed mission with a payload designed to test life-related scientific hypotheses. This mission was initially scoped by MEPAG (Steele et al., 2004). Although some of Steele et al.'s concepts require mobility and some do not, for current planning and costing purposes AFL is assumed by MAPG to include a large rover, based closely on MSL engineering heritage. Although MSL heritage is assumed to be a part of AFL, for the purpose of cost estimation and strategic planning, MAPG limited the use of the term "AFL" to missions with the following characteristics:

1. A substantial roving mission
2. A payload designed to test life-related scientific hypotheses
3. At least one of the following:
    a. Precision sample handling (to allow sub-sampling from rocks, cores, etc)
    b. Multiple life-detection instruments (for corroborative data)
    c. A sampling drill with capability of at least 2 m
4. System sterilization (to allow the mission to be sent to a special region) if needed

Depending on which of these four characteristics are assumed to be present, the "Astrobiology Field Laboratory" could encompass a diverse set of conceptual variants, with different costs, landing site needs, and operational requirements. Cost, complexity, and rationale differ for the many possible combinations of these attributes, and planning for the full suite of possibilities will require significant technology development.

AFL and discovery response

As implied above, the scientific objective of AFL is far from final. MEPAG (2006) proposed that the basic logic to determine if life ever arose on Mars is to first determine the past and present habitability of Mars, then to test for life (either past or present) within an environment of high habitability potential. This suggests that life detection should be at least one primary scientific objective of AFL, and this general logic implies that AFL would be used to respond to a habitability-related discovery made by a prior mission.

As discussed above, there are strongly held divergent opinions within the Mars science community about the minimum threshold for such an AFL-triggering discovery. MSL is NASA's first mission whose primary scientific objective is to quantitatively assess habitability potential. Although a positive MSL result could clearly be the foundation of an AFL mission, the argument has been made that one of our past missions has already delivered sufficiently compelling results, or one of our immediately upcoming missions will do so. Because a decision on what to fly in 2016 is not required for another one to two years, it is not necessary that this question be answered now. Instead, MAPG recommends that the Mars community and the Mars advisory structure engage in discussion of the complexities of this issue for at least the next year and reconsider in 2008. One study that will constitute an important input to this discussion—the "Astrobiology Strategy for the Exploration of Mars"—is currently being carried out by the Space Studies Board of the National Research Council. Until broad-based discussions take place, planning for the Astrobiology Field Lab should retain options for discovery response even as late as surface operations of MSL in 2010.

Can AFL be effectively planned and implemented as early as 2016?

There are three aspects to this question: 1) Can a sufficient scientific justification for AFL be established in time to implement AFL for the 2016 opportunity, 2) Can the competitive instrument procurement processes be carried out in time to support mission engineering, and 3) Will the program be technically and financially able to implement AFL in 2016 given expected constraints?

- Regarding scientific justification, two points are important. First, if the MSL investigations are completed as planned, they will have a relevance to the scientific objectives of AFL. Second, there is a school of thought within the Mars community that scientific results compelling enough to justify AFL will have been obtained by missions to Mars before MSL. Clearly more discussion is needed. Is it possible to build a consensus that AFL either is or is not scientifically contingent on MSL? How strong are the pro and con arguments? If AFL is justified independent of MSL, is it possible to set a baseline design, and then adjust it based on MSL results (e.g., by selection among previously-developed instruments)? Is adjusting the AFL landing site based on MSL results sufficient?
- As pointed out by the MAAC (NRC 2006a), the timing is tight for a significant discovery by MSL to influence the specific language in the Announcement of Opportunity for a 2016 AFL instrument competition. MAPG considered this and found that there are different ways to construct the AFL development timeline, depending in part on what AFL turns out to be. Although the problem is real, it is probably premature to conclude

that a solution is not possible. These timelines are best evaluated in detail by the study team that assesses the AFL science-engineering trade space.

However, it is important to note that in order to achieve 2016 AFL instrument selections with some degree of responsiveness to MSL discoveries, it would definitely be necessary to have a robust instrument development program during the period 2007-2010. This would increase the likelihood that several candidate instruments would have been developed to at least an intermediate TRL level by the time of the AO. There will not be nearly enough time to use MSL discoveries in the early-stage instrument engineering decisions. Having enough instruments to generate a credible response to an instrument competition is an important mechanism for reacting to discoveries and other major developments in the Mars Exploration Program.

- Although it is possible that some variants of AFL could credibly be scheduled as early as 2016, the more capable mission concepts might necessitate a move to the 2018 opportunity or would require resources beyond the assumptions made by MAPG. In addition to the obvious financial benefits, a delay to 2018 would permit valuable feedback on the performance of the MSL engineering system to be used as input to the AFL design. However, since it is clearly possible that the scientific justification for AFL may be established before MSL results become available, it is important to retain the 2016 option for AFL if it is financially possible to do so.

Extant vs. fossil life, and the relationship to planetary protection

Some of the most important recent discoveries by the Mars Program's missions are leading to specific hypotheses relating to fossil, rather than extant, indigenous life. Examples include the evidence of ancient standing water discovered by the MER Opportunity rover, evidence of groundwater found by the Spirit rover, and the Eberswalde delta discovered by MGS. MRO, which has recently begun its primary science mission, is also more likely to make discoveries of relevance to the questions around fossil rather than extant life because of the nature of its instrument complement.

One discovery that would trigger the development of testable hypotheses related to extant life would be the identification of what is referred to in planetary protection policy as a "special region" (see NRC, 2006b; Beaty et. al., 2006). In this context, a special region is one in which Martian organisms might live or in which terrestrial organisms delivered by spacecraft could propagate. To avoid irreversible contamination by live organisms, planetary protection policy requires the use of sterilized spacecraft for the exploration of a special region. As discussed in detail by the MEPAG Special Regions Science Analysis Group (Beaty et. al., 2006), there are no currently known places on Mars that demonstrably fit the special region definition; however, there are incompletely characterized places for which this potential exists, and which need protection until this uncertainty is resolved. Gully regions are examples of such regions, and it is possible that future missions will identify others.

In order to preserve the option to use AFL to test hypotheses related to either extant or fossil life on Mars and retain the option to explore a part of Mars protected as a "special region," it will be necessary to factor in planetary protection considerations. Since direct investigation of a special region would require sterilization under current planetary protection policy, MAPG would endorse a strategy that includes system sterilization in the baseline design for AFL. The sterilization requirement could be dropped in the future if it was unnecessary, but it would be impossible to add in the opposite scenario.

A program strategy to plan for system level sterilization of AFL would impact near-term planning in the areas of technology development, planetary protection implementation, and advance mission design. MAPG recommends that these impacts be considered as part of any future AFL science and engineering studies.

"MSL-copy" or "MSL with new payload"

A possible mission that could be flown in 2016-2018 is a system similar to, or perhaps even identical to, MSL, but to a different location. For planning purposes, it is convenient to think of these conceptually as either an exact copy of MSL, or a mission that is identical to MSL in all respects except that the payload is re-competed. These options could be described as cost-driven missions that deliver a geology/geochemistry/mineralogy payload with the same rover, sample acquisition system, planetary protection and organic cleanliness requirements as for MSL. Such a mission could be quite valuable in evaluating habitability in a different location, and possibly with more advanced instrumentation than MSL. It is possible that in a re-competed payload scenario, a life-detection instrument could be selected (however, unless sterilization is also added, the mission would be restricted to investigations related to fossil life). The MAPG considers this MSL-like mission to be a valuable planning option, but it should not be considered a substitute for AFL.

A complete evaluation of the science and engineering options associated with a large landed mission in 2016 or 2018 requires detailed study by a community-based science team. Such an analysis would give rise to a decision strategy for use of MSL results and a case for a 2016 or 2018 AFL mission. This activity is proposed for FY07.

4. MSR Technology Investment (Recommendation #4)

(4) Devise a strategy to implement the Mars Sample Return mission, and ensure that a program is started at the earliest possible opportunity to develop the technology necessary to enable this mission.

Under the current program funding levels and priority of missions, the mission queue does not include MSR before the 2020's for an orbiter/landers/return sequence nor a focused technology development starting before 2014. Nevertheless, the program could further consider the potential of moving MSR earlier if circumstances were to change the nature of the program. Such changes could include increase of funding for Mars exploration; unexpected and compelling results from MRO, Phoenix or MSL; increased emphasis on preparation for humans to Mars; or substantial international participation. Within the current budget, if modified priorities were to displace the entire post-MSO program with MSR, it could be implemented in a split mission of lander then orbiter, or vice versa, possibly as early as 2018/2020. For a 2018/2020 MSR, it is thought that focused technology development would need to start in FY08, but that it could be funded at a relatively modest level (e.g., $25M) for the first two years. (The technology program is ready to restart based on a detailed plan that was “tabled” in FY05.) A commitment to that first two years of technology development would be necessary to preserve MSR as an option in the second decade and demonstrate NASA's commitment to MSR sufficiently to re-invigorate international discussions.

For an MSR mission scheduled early in the third decade, there are certain things that could be done with the intervening missions that could increase the scientific value of MSR, but there is not much that can be done to reduce the cost. One obvious example is that caching of samples by AFL 2016 or 2018 could potentially improve the quality of the sample collection returned by MSR by allowing more information to go into sample selection decisions. This option would keep MSR planning active and enable potential sample selection with the most sophisticated suite of instruments to date, at minor incremental cost to AFL. Development of comprehensive planetary protection solutions for AFL would also contribute to MSR needs.

5. Decision Strategy for 2016 (Recommendations #5a, #5b)

(5a) Develop and articulate criteria for distinguishing between the three options for missions to launch in 2016. (5b) Similarly, define a strategy that addresses the short lead time between science results obtained from the Mars Science Laboratory and selection of the mission to fly in 2016.

There are multiple mission options to be considered for launches in 2016 and 2018, but the decisions about which missions to launch, and in which sequence, depend on information that is not yet available. The outcome of the competition for the 2011 Scout mission may be a factor, since there will be a need to avoid duplication of science accomplished by the subsequent missions. In addition, the decisions will require further detail on the cost-performance tradeoffs for the 2016-2018 candidate missions. Finally, it will be necessary to incorporate scientific results from the on-going Mars missions, most importantly, from the Mars Reconnaissance Orbiter, which has just entered its science mapping phase in early November 2006. Rather than undertaking an effort to map out the various planning contingencies at this time, the MAPG recommendation is to consider 2016-2018 in light of results from the three considerations above, along with updated program context. A component of the analysis will be the development of decision criteria, including the feasibility and timing associated with feed forward of science results.

Analysis of the 2016 flight opportunity should be continued through 2007 and finalized in 2008.

UPDATED MARS PROGRAM ARCHITECTURE

Based on an analysis of the Mars Program’s significant recent discoveries and its main strategies and priorities for moving forward, McCleese et al. (2006) established a primary flow of major scientific investigations for the exploration of Mars. This scientific flow was consistent with an assumed overall programmatic financial constraint and assumptions of future technology readiness to derive a set of next decade architecture options (Figure 3a of McCleese et al., 2006). Since then, the following changes have occurred:

- NASA HQ has decided that the 2011 launch opportunity will be a Scout mission. The Announcement of Opportunity was released in mid-2006, and as of this writing, the proposals received in response to the AO are in review.
- The NRC has provided formal feedback on the McCleese et al. (2006) report.
- The financial model for MEP has been modified slightly.
- The MEP has improved its understanding of the engineering trade space for the Mars Science Orbiter and the Astrobiology Field Lab mission concepts.

Using these refinements, MAPG proposes the updated architecture shown in Figure 2.

- 2013 Mars Science Orbiter (MSO). Two compelling classes of atmospheric science investigations have been described by the MEPAG Science Analysis Group report on MSTO (Farmer et al., 2006) and will be considered for MSO. In addition, two classes of geophysical investigations are thought to be possible for MSO, neither of which have yet been completely studied: orbital radar, in follow-up to the MARSIS and SHARAD experiments on MEX and MRO, respectively; and one or more small landed elements for network science. The mission selection through the Mars Scout competition for launch in 2011 will be a major factor in mission content decisions for MSO.
- 2016-2018. The second decision point determines content for the 2016 and 2018 opportunities. Figure 2 shows four main options, consideration of which is dependent both on scientific results and early programmatic decision-making. The options include the Astrobiology Field Lab (or MSL-copy or MSL with new payload), twin Mid-Rovers, a network mission, and a Scout. There are several attractive combinations involving these missions for the two launches, however, it is important to recognize that current financial assumptions will permit no more than two of the four missions shown in 2016-2018, and not all combinations of two missions fit within financial guidelines.

Given present financial assumptions, it is not possible to fly all of the missions recommended by the NRC during the period 2013-2018. For example, a very attractive mission sequence from the point of view of science would be 2013-MSO, 2016-Network, 2018-AFL, but this architecture would require a significant budget augmentation. In the absence of such an augmentation, financial constraints will force us to reduce our expectations.

The notional placement of MSR in the "2020 or later" time frame indicates the program's intent to get MSR into the mission sequence after the in-situ missions in 2016-2018 and to restart technology development in the second decade. Placement of MSR in the flight architecture of the following [or third] decade may be useful to encourage technological development, support international partnership discussions, and ensure continuing dialog about MSR options for the future.

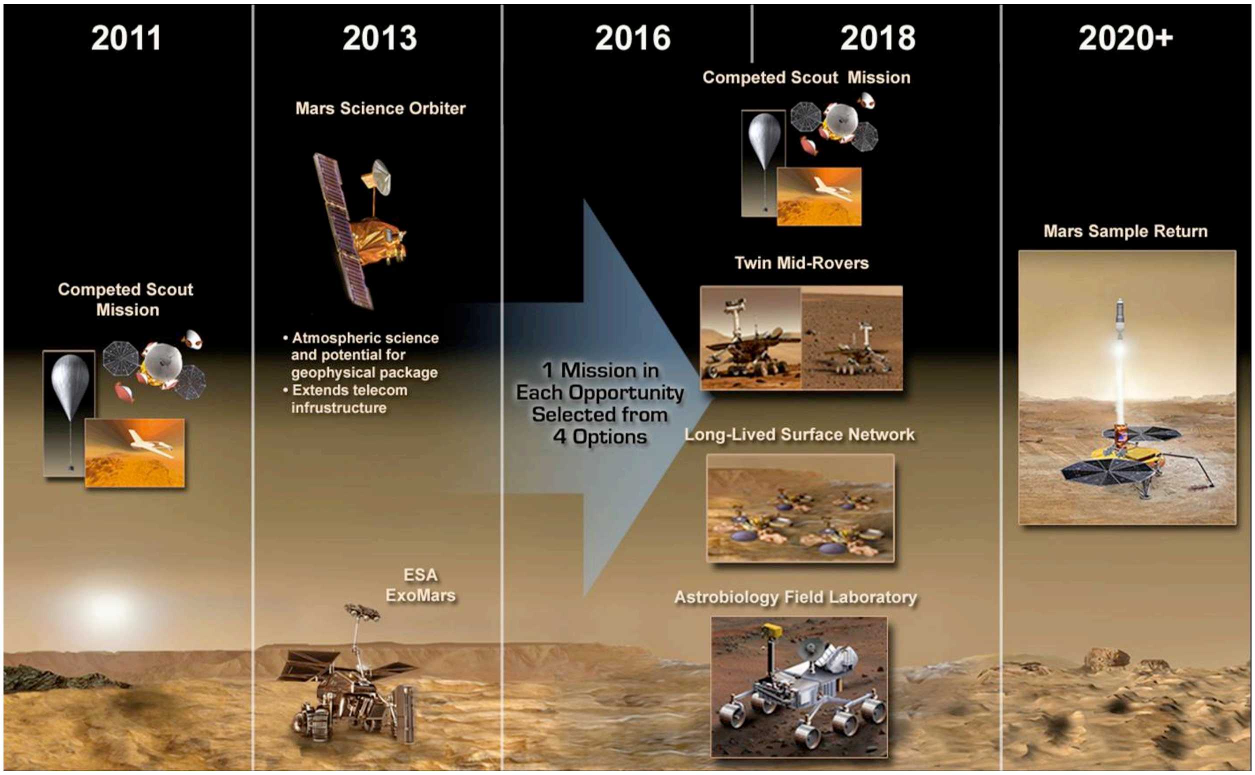

Figure 2. *Proposed next decade Mars Program flight architecture. It is assumed that ESA's ExoMars mission will fly in 2013. For the 2016 and 2018 launch opportunities, there are several possible mission options, and multiple ways to sequence these options. The Mars Exploration Program plans further definition of these options during FY07. Mars Sample Return is shown in the 2020+ period. Although the specific timing cannot be planned this far in advance, this mission is an intrinsic part of the program's scientific logic.*

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APPENDIX 1. SUMMARY OF RECOMMENDATIONS MADE BY NRC (2006a).

NRC Report: Assessment of NASA's Mars Architecture 2007-2016			
	RECOMMENDATION	**SMD RESPONSE 7/10-06**	**MAPG SCOPE**
1	Include the Mars Long-Lived Lander Network in the mix of options for the 2016 launch opportunity.	AGREE TO CONSIDER	ANALYSIS REQUESTED BY MAPG
2	Consider delaying the launch of the Astrobiology Field Laboratory until 2018 to permit an informed decision of its merits and the selection of an appropriate instrument complement in the context of a mature consideration of the results from the Mars Scien	AGREE TO CONSIDER	ANALYSIS REQUESTED BY MAPG
3	Establish science and technology definition teams for the Astrobiology Field Laboratory, the Mars Science and Telecommunications Orbiter, the Mid Rovers, and the Mars Long-Lived Lander Network as soon as possible to optimize science and mission design in	WILL ACT IN 2007	NO ACTION BY MAPG NEEDED
4	Devise a strategy to implement the Mars Sample Return mission, and ensure that a program is started at the earliest possible opportunity to develop the technology necessary to enable this mission.	CONCUR WITH PHILOSOPHY	ANALYSIS REQUESTED BY MAPG
5a	Develop and articulate criteria for distinguishing between the three options for missions to launch in 2016.	WILL ACT IN 2007	ANALYSIS REQUESTED BY MAPG
5b	Similarly, define a strategy that addresses the short lead time between science results obtained from the Mars Science Laboratory and selection of the mission to fly in 2016.		ANALYSIS REQUESTED BY MAPG
6	Clarify how trade-offs involving mission costs versus science were made for the various launch opportunities to justify the rationale behind the proposed sequence of specific missions and the exclusion of others.	OVERVIEW RESPONSE GIVEN	ANALYSIS REQUESTED BY MAPG
7	Maintain the Mars Scouts as entities distinct from the core missions of the Mars Exploration Program. Scout missions should not be restricted by the planning for core missions, and the core missions should not depend on selecting particular types of Scout	OVERVIEW RESPONSE GIVEN	
8	Immediately initiate appropriate technology development activities to support all of the missions considered for the period 2013-2016 and to support the Mars Sample Return mission as soon as possible thereafter.	WILL ACT IN 2007	NO ACTION BY MAPG NEEDED
9a	Ensure a vigorous research and analysis (R&A) program to maintain the scientific and technical infrastructure and expertise necessary to implement the Mars architecture.	CONCUR WITH PHILOSOPHY	NO ACTION BY MAPG NEEDED
9b	Encourage collaboration on international missions.		
10	Include the Mars Long-Lived Lander Network in the mix of options for the 2016 launch opportunity.	SAME AS #1	ANALYSIS REQUESTED BY MAPG
11	If the Mars Long-Lived Lander Network cannot be implemented in the period under consideration, provide for an effort to make some of the highest-priority measurements on the landed missions that are included in the proposed Mars architecture.	AGREE TO CONSIDER	ANALYSIS REQUESTED BY MAPG
12	Ensure that the primary role of the Mars Science and Telecommunications Orbiter is to address science questions, and not simply to serve as a telecommunications relay. This distinction is particularly important with respect to the required orbital paramet	CONCUR WITH PHILOSOPHY	NO ACTION BY MAPG NEEDED

APPENDIX 2. NASA LETTER RESPONSE (DATED JULY 10, 2006) TO NRC.

National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

Reply to Attn of: SMD/Planetary Science Division

Dr. Reta F. Beebe
Chair
Mars Architecture Assessment Committee
Space Studies Board
National Research Council
Washington, DC 20001

Dear Dr. ~~Beebe~~: Rita

Thank you for the Mars Architecture Assessment Committee (MAAC) report. Your report provides a thorough review of the "Mars Program Plan: The Coming Decade" which was developed by the Mars Advanced Planning Group (MAPG) and reviewed by the Mars Exploration Program Analysis Group (MEPAG). Your thorough and insightful analysis of the architecture is greatly appreciated. It is extremely valuable to know that the MAAC found no substantial omissions or errors in the draft architecture, and your astute comments and recommendations for "fine tuning" the next decade will be taken into consideration as the Mars Program finalizes the next decade architecture for the robotic exploration of Mars.

The Science Mission Directorate fully agrees with your assessment that "the theme of Mars as a potential abode of life is well served by the proposed architecture, that theme being a primary focus of the Phoenix, Mars Science Laboratory (MSL), Astrobiology Field Laboratory (AFL), and Mid Rover missions. Similarly, the second theme, water, atmosphere, and climate on Mars, is also well served and is a focus for the Phoenix, MSL, Mars Science and Telecommunications Orbiter, and AFL missions." Your assessment that "the third theme, structure and evolution of Mars, is not well addressed by the proposed architecture" is also accurate. The Mars Exploration Program (MEP) constrained the architecture to a decade, 2006-2016, thus placing equal emphasis on all the themes became impractical until budgets and discoveries in later years are taken into account. However, during the upcoming reviews and finalization, the MAAC Report's findings will be taken into account on the third theme.

The next steps include the Mars Program requesting MAPG and MEPAG to review the Mars architecture, taking the MAAC Report into consideration, which will then be used to finalize the "Mars Program Plan: The Coming Decade." Additionally, the MAAC support for the basic architecture now enables realignment of technology plans in order to optimize our capabilities for future missions, focusing on the 2013 and 2016 mission alternatives. The attachment contains some comments about the report and specific abbreviated responses to your specific recommendations. Additional updates will be provided through regularly scheduled Committee on Planetary and Lunar Exploration meetings.

Thank you again for your time and effort in producing this superb report. Its thorough analysis and astuteness will be of great assistance as the MEP considers how best to rebalance the program over the coming decade.

Si

M. L. Cleave

Mary L. Cleave
Associate Administrator for
Science Mission Directorate

Enclosure

cc:
SMD/Dr. Hartman
- Dr. Hertz
- Dr. Allen
- Mr. Williams

Planetary Science Division/Mr. McCuistion
- Dr. Meyer

JPL/Dr. Li
JPL/Dr. Beaty

The development of a Mars architecture was started in response to a significant reduction in resources available to the Mars Exploration Program (MEP) – a new architecture was needed for the next decade. Initially, the Mars Advanced Planning Group (MAPG) was considering years out to 2020, which included network missions and sample return, but the President's proposed 2007 budget (released in February 2006) defined a budgetary growth rate below inflation, therefore determining the affordability of missions beyond 2016 became untenable. Additionally, considering the potential for paradigm-altering discoveries, the architecture was constrained to 2016, which could be proposed with adequate certainty based on the President's 2007 budget. The MEP has not omitted two high-priority missions recommended by the decadal survey, but has identified a network mission and sample return as missions after 2016. In alignment with the Mars Architecture Assessment Committee (MAAC) Report recommendations, the MEP will consider the possibility of a network mission as an alternative in 2016. The MEP will also continue to pursue international collaborations, which may advance both a network mission and sample return mission. Furthermore, MEP understands the difficulty in having sufficient information from MSL exploration to help guide the nature of the Astrobiology Field Laboratory (AFL), and will reconsider whether that mission should be deferred to 2018.

The MEP appreciates your endorsement of the importance of the Research and Analysis (R&A) and technology programs. In order to focus on the architecture, these program elements were purposely not addressed, not for a lack of perceived importance, but because no changes to the competitive research and analysis (R&A) programs are planned, and for the inability to restructure technology plans until the architecture is finalized.

The following provides responses to your recommendations to Science Mission Directorate's (SMD) evaluation questions:

SMD QUESTION:
IS THE MARS ARCHITECTURE REFLECTIVE OF THE STRATEGIES, PRIORITIES, AND GUIDELINES PUT FORWARD BY THE NRC'S SOLAR SYSTEM EXPLORATION DECADAL SURVEY AND RELATED SCIENCE STRATEGIES AND NASA PLANS?

- ***MAAC Recommendation:*** **Include the Mars Long-Lived Lander Network in the mix of options for the 2016 launch opportunity.**
  Agree to consider a Mars Long-Lived Lander Network in 2016.

- ***MAAC Recommendation:*** **Consider delaying the launch of the Astrobiology Field Laboratory until 2018 to permit an informed decision of its merits and the selection of an appropriate instrument complement in the context of a mature consideration of the results from the Mars Science Laboratory and other prior missions.**
  This will be taken into consideration.

- *MAAC Recommendation:* **Establish science and technology definition teams for the Astrobiology Field Laboratory, the Mars Science and Telecommunications Orbiter, the Mid Rovers, and the Mars Long-Lived Lander Network as soon as possible to optimize science and mission design in concert with each other. (This model has been employed successfully by the heliospheric community.)**
Science Definition Teams (SDT's) are used successfully by MEP for all core missions. They specifically scope a mission for its objectives, required resources, and establish a feasible straw-payload for competition, thus "locking in" the science scope of the mission. Executing these detailed studies now may set requirements too early in a given mission's life cycle. However, Science Analysis Groups (SAG) are typically established earlier than an SDT, and have been helpful in the past defining possible mission options without limiting or defining mission scope. A SDT will be used to set directions for coordinating the science synergy and technology development in the near future for MSO (2007), and SAGs will be used for mission options in the 2016 opportunity soon thereafter.

- *MAAC Recommendation:* **Devise a strategy to implement the Mars Sample Return mission, and ensure that a program is started at the earliest possible opportunity to develop the technology necessary to enable this mission.**
We recognize the ultimate benefit of a sample return and consider development of long-lead time technologies in order to be prepared to accomplish sample return when resources are available, either through international collaboration or changes in funding priority.

SMD QUESTION:
DOES THE REVISED MARS ARCHITECTURE ADDRESS THE GOALS OF NASA'S MARS EXPLORATION PROGRAM AND OPTIMIZE THE SCIENCE RETURN, GIVEN THE CURRENT FISCAL POSTURE OF THE PROGRAM?

- *MAAC Recommendation:* **Develop and articulate criteria for distinguishing between the three options for missions to launch in 2016. Similarly, define a strategy that addresses the short lead time between science results obtained from the Mars Science Laboratory and selection of the mission to fly in 2016.**
An activity will be started in 2007 to develop the differentiation criteria and timing rationale.

MAAC Recommendation: **Clarify how trade-offs involving mission costs versus science were made for the various launch opportunities to justify the rationale behind the proposed sequence of specific missions and the exclusion of others.**
The entire planning process was conducted by the Mars Program's advanced planning office, iterated numerous times, and developed under scientific and programmatic guidance from the Program at NASA Headquarters. Trades were specifically conducted to determine which missions would fit into the budget profile and when, with respect to previous missions and potential scientific discoveries. The National Academy's Decadal

Survey was also used in helping set scientific priorities and missions during this process. However, uncertainties in out-year budget inflation rates and to-be-defined mission costs made it appropriate for the planning team to limit mission-per-launch opportunity planning to 2016.

- *MAAC Recommendation:* **Maintain the Mars Scouts as entities distinct from the core missions of the Mars Exploration Program. Scout missions should not be restricted by the planning for core missions, and the core missions should not depend on selecting particular types of Scout missions.**
  This is the basic premise for Scouts, which will not change. However, what may be included on future core missions may be altered so as not to duplicate what will be accomplished by a particular selected Scout mission. Additionally, "buying power" in the future will dictate the number and frequency of opportunities that can be set aside for competed Scout missions. Scouts remain an important element in Mars exploration, and will continue to bring innovative ideas for exploration at modest cost.

- *MAAC Recommendation:* **Immediately initiate appropriate technology development activities to support all of the missions considered for the period 2013-2016 and to support the Mars Sample Return mission as soon as possible thereafter.**
  One of the drivers for developing the Mars architecture was to assist in properly focusing technology development activities. Over the next year, we plan to charter a technology assessment group, which will include broad science and technology community involvement, to prioritize the technology developments needed for the next 10-15 years.

  MAAC Recommendation: **Ensure a vigorous research and analysis (R&A) program to maintain the scientific and technical infrastructure and expertise necessary to implement the Mars architecture, and encourage collaboration on international missions.**
  Agreed. The competitive Mars Fundamental Research and Mars Data Analysis Programs will continue on track.

SMD QUESTION:
DOES THE MARS ARCHITECTURE REPRESENT A REASONABLY BALANCED MISSION PORTFOLIO?

- *MAAC Recommendation:* **Include the Mars Long-Lived Lander Network in the mix Of options for the 2016 launch opportunity.**
  This will be studied (see above).

- *MAAC Recommendation:* **If the Mars Long-Lived Lander Network cannot be implemented in the period under consideration, provide for an effort to make some of the highest-priority measurements on the landed missions that are included in the proposed Mars architecture.**
  This will be considered an option.

- ***MAAC Recommendation:* Ensure that the primary role of the Mars Science and** Telecommunications Orbiter is to address science questions, and not simply to serve as a Telecommunications relay. This distinction is particularly important with respect to the required orbital parameters that are adopted. This has been, and remains, the intention of MEP.